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TRAPPING AND DIFFUSION MECHANISM IN ALUMINUM ALLOYS.

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We have studied Al(Cu), Al(Mg) and Al(Ag) alloys. to determine the μ^+ trapping sites, and how impurity distortions affect these sites. Cu (monovalent) contracts the Al lattice, Mg (divalent) expands it, and Ag (monovalent) has almost no effect. Fitting to a two-state model we obtained a temperature exponent β of 0.93(26 for zero field and 1.16(14) for a longitudinal field, where $\beta = 1$ implies a one-phonon induced diffusion process. The measured second moment in Al(Mg) indicates a changing trapping site, which was confirmed by zero and longitudinal field studies. Comparing the Al(Mg) results with earlier Al(Cu) data, two types of sites can be identified: those which are distant from the defect and depend on the magnitude but not the sign of the deformation, and those close tó Mg. Ag produces no lattice distortion, and its weaker depolarization suggests a different trapping mechanism.

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Introduction

We have used longitudinal and zero field μSR techniques to study muon motion and trapping sites for a range of alloying impurities in aluminum. These impurities were chosen for their differing lattice perturbations. Cu contracts the Al lattice, Mg expands it, while Ag has little effect /1/. On the other hand Cu and Ag are monovalent and therefore are expected to produce deeper muon traps in Al than does Mg which is divalent /2/. Our results add to those of Kehr et al. /3/ who have made an extensive study of a variety of Al alloys in transverse magnetic fields.

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Experiment

The samples were Al(Cu420ppm), Al(Mg1000ppm), and Al-(Ag1000ppm) which we used for transverse field measurements in a previous study /4/. Each sample was made of 3 separate plates for a total thickness of 9 mm. These measurements were taken over a temperature range from 4.9K to 300K. These experiments were carried out at the stopping muon beam at Brookhaven National Laboratory.

Results

Fig. 1 shows the zero and longitudinal field result for Al(Cu).

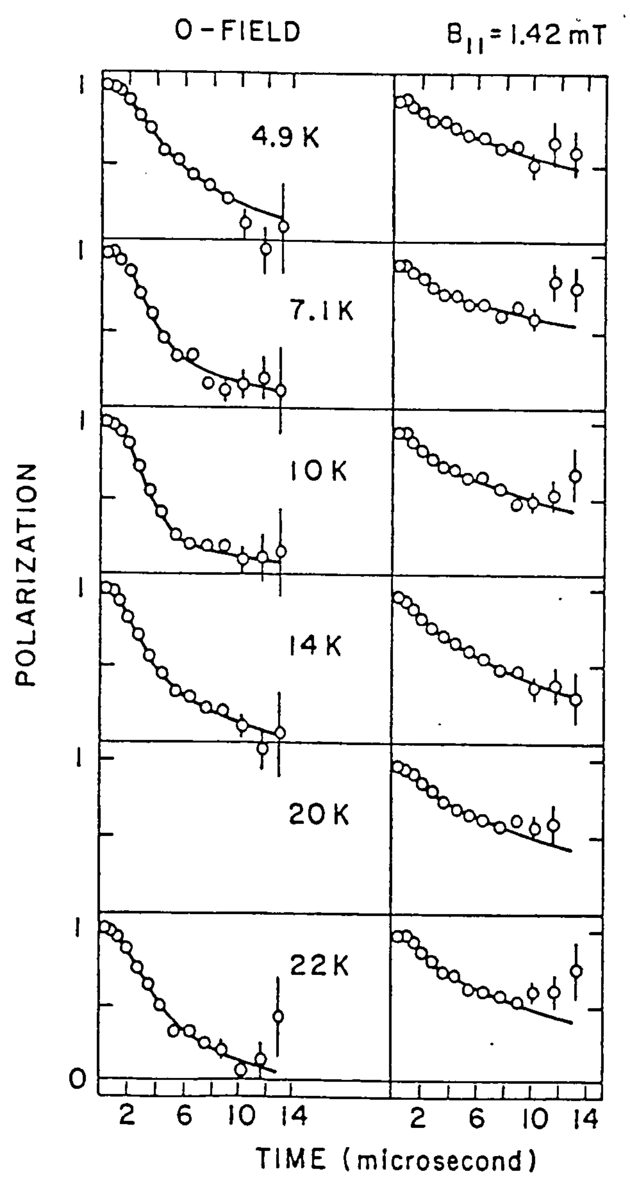

Fig. 1. Zero field and longitudinal field muon polarization as a function of time in Al(Cu 420 ppm).

Since the polarization decreases monotonically for all these curves (with the possible exception of 22K) one concludes that the muon is not stationary for this temperature range. We obtained second moments and trapping and escape rates from the application of the two state model /5/. This is the first time to our knowledge that the two state model has been applied to longitudinal field data, and the agreement with the zero field results is gratifying. The trapping rates were fit to $\tilde{n} = \tilde{n}_0 T^{\beta}$, yielding $\beta = 0.93(26)$ for zero field and 1.16(14) for longitudinal field (Fig. 2).

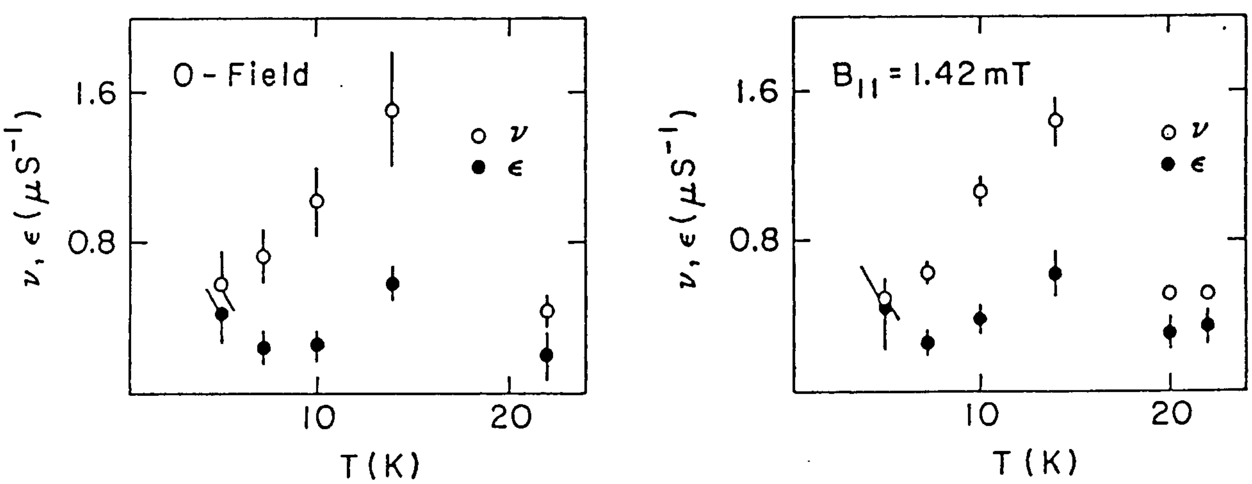

Fig. 2. The trapping (ν) and escape (ε) rates determined in zero field and longitudinal fields as a function of temperature for Al(Cu).

These are consistent with $\beta = 1$ expected for a one-phonon induced hopping process. Kehr et al. /3/ have seen similar low temperature behavior for Al(Mn). From the change in the depolarization parameter Δ_z the existence of more than one type of trapping site is evident. Between 4.9K and 14K a tetrahedral site with 10% nearest neighbor relaxation is consistent with the value of Δ_z obtained. This 10% relaxation also yields the volume expansion cited by Kehr et al. /3/ for H in Al. Above 20 K the measured Δ_z is too large for the expected sites. Muons having a copper nearest neighbor would not explain the result since the copper moment is less than the aluminum moment. The increased Δ_z could be explained if the lattice is locally contracted near the muon. Copper is known to contract the aluminum lattice.

For Al(Mg) we obtained the transverse field results shown in Fig. 3, and the zero and longitudinal field results in Fig.4. For 10 K, 82 K, and 180 K the muon is stationary while at 53K there is motion. We have obtained the transverse depolarization parameter Δ_x and the activation energies for escape from sites for the various temperature regions. Between 10 and 60K Δ_x = 0.317(7) μs^{-1} in approximate agreement with a tetrahedral site assignment, if it is taken into account that the 15mT field is not sufficient to completely decouple the electric quadrupole interaction. The activation energy here is 20(1) meV. For zero field at 10K Δ_z is about .37 μs^{-1} which agrees with the calculated value of 0.369 μs^{-1} for T site occupancy. At 80 K we observe Δ_z = .25 μs^{-1} which is consistent with octahedral site occupation assuming a near neighbor lattice dilation of order 13%. It should be noted that the transverse field results show an additional plateau around 180K with Δ_x = 0.150(13) μs^{-1} which may correspond to a deeper trap. The longitudinal field data at 180 K demonstrate that the peak seen in the transverse field data at the same temperature corresponds to a stationary muon in a site with second moment very similar to that for an octahedral site. Above 200 K motional narrowing is observed for which an activation energy of 95(34) meV is obtained.

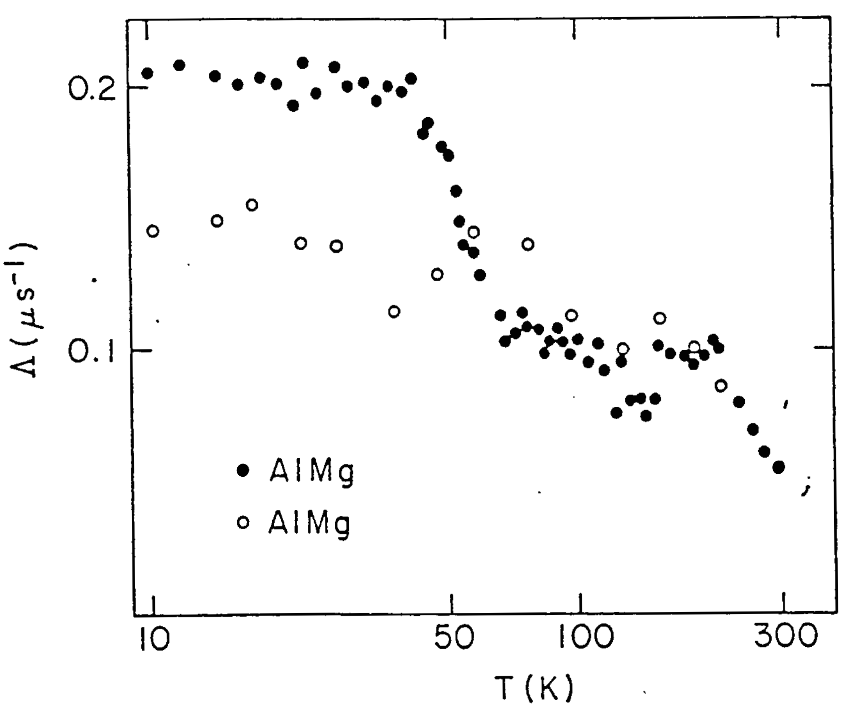

Fig. 3. Transverse depolarization rate Λ as a function of temperature for Al(Mg) and Al(Ag).

The transverse data for Al(Ag) are also shown in Fig. 3. For low temperatures the transverse and zero field results are consistent with octahedral site trapping. At 17 K there is recovery in the zero field data indicating a lack of detrapping.

Conclusions

We have demonstrated that the longitudinal field technique can yield reliable and consistent trapping rates. Using this technique in conjunction with the zero field technique one obtains the muon trapping rate versus

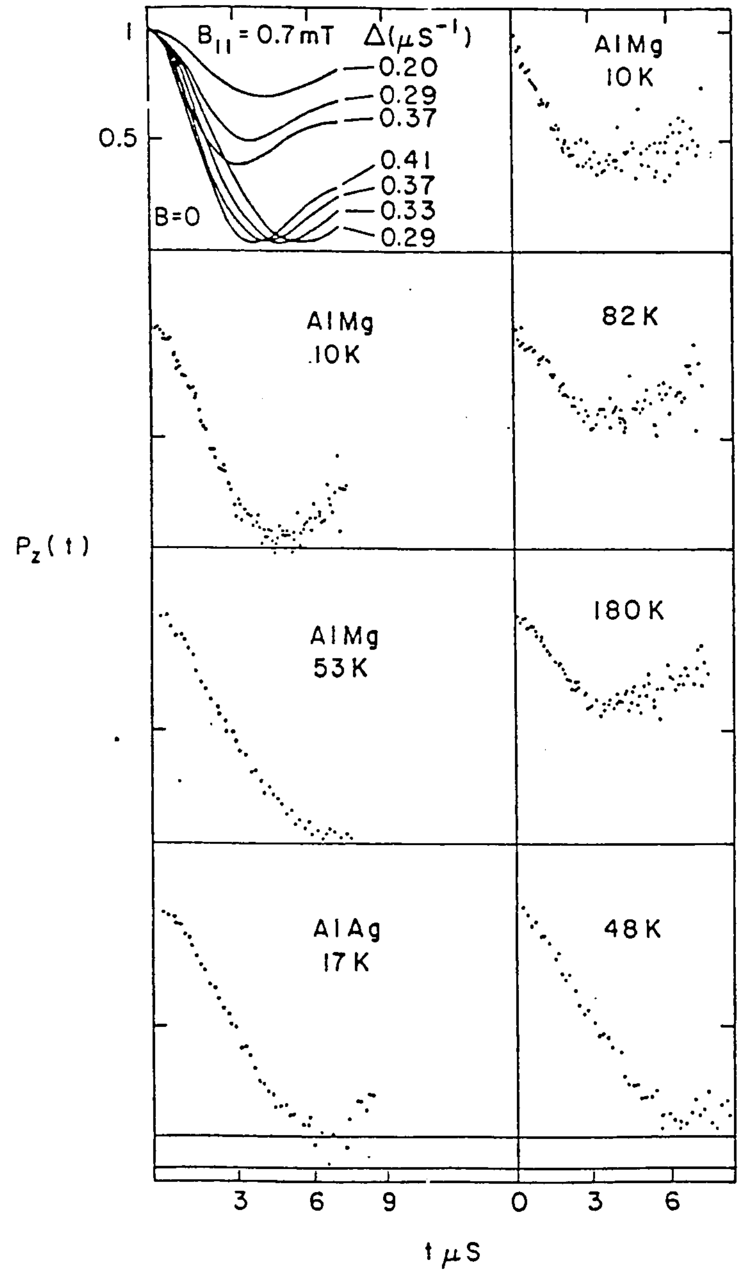

Fig. 4. In the upper left are theoretical depolarization curves for longitudinal and zero fields for various values of Δ. The other curves are experimental results for zero field (10 K, 53 K) and longitudinal field (10 K, 82 K, 180 K) in Al(Mg), and for zero field (17 K, 48 K) in Al(Ag).

T. The observation of a linear T dependence for this rate in Al(Cu) adds evidence for the conclusion that one-phonon assisted hopping is the usual diffusion mechanism at temperatures of order 10 K. Our observed depolarization rates for T>5K in both Al(Cu) and Al(Mg) are consistent with tetrahedral traps. It is interesting to note that Al(Ag) which does not have large local strains does not appear to have these traps. Therefore, the existence of tetrahedral trapping sites traps are more likely to be associated with strain effects than with valence effects.

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